# MAGNETIC PULSE WELDING METHOD AND APPARATUS FOR SEALING A VESSEL AND A SELLED VESSEL.

## FIELD OF THE INVENTION

This invention relates to a method and apparatus for sealing containers and in particular, for sealing vessels by a pulsed magnetic force (PMF).

## BACKGROUND OF THE INVENTION

A vessel such as a container, canister, tank, flask, etc. used, for example, for gas and/or liquid storage is usually produced by manufacturing a vessel body portion and a cover portion separately. For sealing the vessel, welding or crimping methods can be used for coupling the cover portion to the vessel body portion. Welding hereinafter refers to a process in which two opposite surfaces of first and second workpieces form a physical joint, thereby become integrated with one another owing to mutual diffusion of their atoms. In turn, crimping refers to such joining of two workpieces, when a surface of at least one of the workpieces becomes wavy, bent, or pinched so as to provide a "pure" mechanical joint between the two workpieces without interpenetration of the atoms of the first workpiece into the body of the second workpiece.

The crimping is usually made by stamping or rolling. However, various crimping techniques are also known in the art which utilize the force generated by a transient magnetic field for sealing vessels.

For example, U.S. Pat. No. 3,581,456 to Gere describes a method for forming a closure on the neck finish of a filled container which utilizes the force generated by a transient magnetic field. The skirt of a cap, positioned on the neck of the container, is urged by the field against the neck finish so as to cause the skirt

to conform to the contours of the neck finish and to thereby hold the cap in engagement with the neck finish upon the neck of the container.

U.S. Pat. No. 3,957,005 describes a method for making a metal can end that includes a body portion of substantially uniform metal thickness and a peripheral flange of reduced metal thickness. The can end is formed from relatively thin sheet material, such as aluminum sheet or the like, by punching or shearing a blank or disc from the sheet and forming the disc into a cup which is subjected to an ironing operation to reduce the thickness of the peripheral portion thereof and increase its projecting length. The ironed cup is then subjected to mechanical pressing, or magnetic discharge forming, to shape the peripheral portion into a curvilinear flange which is adapted to be double seamed to the can body.

U.S. Pat. No. 4,934,552 to Koide et al. describes a method for producing a sealed vessel including a cylindrical body portion having an open end, and a cover fitting in the open end of the body portion. The sealed vessel is produced by pressing the open end of the body portion from the outside of the body portion to an outer peripheral surface of the cover provided with at least one of annular grooves around the outer peripheral surface of the cover. In the case of using an electromagnetic force as the means for press-working, a part of the body portion is strictly and air-tightly fixed to the annular grooves in a moment and thus the sealed vessel is produced.

U.S. Pat. No. 5,191,775 to Shiina et al. describes a technique for sealing a refrigerating-medium storage vessel which comprises a tubular body having a bottom and an open upper end portion, and a closure fitted in the open end portion. The open end portion is constricted and crimped by electromagnetic forming and is thereby secured to the closure by beading and matching groove. U.S. Pat. No. 5,191,775 states that the method does not employ welding for joining the closure to the body.

U.S. Pat. No. 5,671,522 to Aronne describes another crimping technique for sealing a container by magnetic pulse forming techniques. The container is closed by means of a pair of specially constructed end caps each having annular recesses

formed around their circumference. The ends of the container are engaged within the recess and joined by magnetic pulse forming. The magnetic pulse force is asserted radially inward against a mandrel which mates with a depression formed in the caps.

The conventional welding is usually carried out by a gas welding apparatus, laser or any other conventional welding technique. It is known in the art that the gas welding techniques suffer from different disadvantages, e.g., the vessel body must be made of a heatproof material, etc.

It is known in the art (see, for example, U.S. Pat. No. 5,824,998 to the Assignee of this application) that pulsed magnetic forming techniques can also be used for cold welding two metal workpieces.

## SUMMARY OF THE INVENTION

Despite the prior art in the area of sealing containers by magnetic pulse forming techniques, there is still a need in the art for, and it would be useful to have, a novel method and apparatus for sealing vessels by utilizing magnetic pulse force (PMF). It would be advantageous to facilitate joining a vessel body and a cover by cold welding providing mutual diffusion of their atoms.

Thus, according to one broad aspect of the invention there is provided a method of sealing a vessel, comprising:

(a) providing a vessel's body having at least one open end;

(b) providing a cover having a welding part, where said welding part has a diameter less than the inner diameter of the vessel's body;

(c) placing the cover within said at least one open end of the vessel's body, thereby an air gap is formed between said vessel's body and the welding part of said cover;

(d) providing a welding induction coil around said vessel's body at the place where the welding part of the cover is located; and

(e) energizing said welding induction coil to generate a pulsed magnetic force sufficient to cause bending a portion of the vessel's body in a radially inward direction around the cover in said air gap, said pulsed magnetic force has such a value so to provide mutual diffusion of atoms of the vessel's body and the cover at their impact, thereby welding said vessel's body and the cover to each other.

According to another broad aspect of the present invention, there is provided a sealed vessel comprising:

a vessel's body, where said vessel's body had at least one open end before the vessel was sealed;

a cover having a welding part, where said welding part has a diameter less than the inner diameter of the vessel's body, thereby an air gap was provided between said vessel's body and the welding part of said cover placed within the said at least one open end of the vessel's body before the vessel was sealed,

wherein said cover being welded to the vessel's body by a pulsed magnetic force causing bending a portion of the vessel's body in a radially inward direction around the cover in said air gap, said pulsed magnetic force has such a value so to provide mutual diffusion of atoms of the vessels body and the cover at their impact.

When require, the cover can include also a brim part, where a value of a diameter of the cover at the brim part is about the value of an inner diameter of the vessel's body, thereby to provide holding the cover within the vessel's body.

According to yet another broad aspect of the present invention, there is provided a welding induction coil comprising at least a one-turn coil having two electrodes configured for applying pulsed high voltage thereacross,

wherein said welding induction coil is configured for use with an apparatus for sealing a vessel having:

wherein said welding induction coil is configured for use with an apparatus for sealing a vessel including:

a vessel's body having at least one open end, and

a cover having a welding part, where said welding part has a diameter less than the inner diameter of the vessel's body, thereby providing an air

gap between said vessel's body and the welding part of said cover when the cover is placed within said at least one open end of the vessel's body;

wherein said welding induction coil is capable to generate a pulsed magnetic force causing bending a portion of the vessel's body, placed within a working zone of said welding induction coil, in a radially inward direction around the cover in said air gap, said pulsed magnetic force has such a value so to provide mutual diffusion of atoms of the vessel's body and the cover at their impact, and thereby to weld said cover to the vessel's body.

There has thus been outlined, rather broadly, the more important features of the invention in order that the detailed description thereof that follows hereinafter may be better understood. Additional details and advantages of the invention will be set forth in the detailed description, and in part will be appreciated from the description, or may be learned by practice of the invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

**Fig. 1A** and **Fig. 1B** illustrate an exploded view and a cross-sectional view of a vessel before a sealing process, according to one embodiment of the invention;

**Figs. 2A-2D** illustrate a sequence of stages of the welding process, according to an embodiment of the invention;

**Fig. 3A** and **Fig. 3B** illustrate exemplary images obtained from the examination under an optic microscope of an etched interface cross-section of the joint between a vessel's welding portion and a cover's welding part made of low carbon steel and aluminum, respectively;

**Fig. 4A** and **Fig. 4B** illustrate an exploded view and a cross-sectional view of the vessel before a welding process, correspondingly, according to another embodiment of the invention;

**Fig. 5** illustrates a cross-sectional view of the vessel before a welding process, according to a further embodiment of the invention;

**Fig. 6** illustrates a cross-sectional view of the vessel before a welding process, according to yet another embodiment of the invention;

**Figs. 7A-7C** illustrate cross-sectional views of the vessel before a welding process, according to a still further embodiments of the invention; and

**Fig. 8A** and **Fig. 8B** illustrate a prospective view and a cross-sectional view of the welding induction coil, correspondingly, according to an embodiment of the invention.

## DETAILED DESCRIPTION OF THE INVENTION

The principles and operation of a method and an apparatus according to the present invention may be better understood with reference to the drawings and the accompanying description, it being understood that these drawings are given for illustrative purposes only and are not meant to be limiting. The same reference numerals will be utilized for identifying those components which are common in the vessel and the working coil shown in the drawings throughout the present description of the invention. Dimensions of vessel, thickness of the walls of the vessel and cover as well as gaps between the vessel and cover and their portions may be exaggerated for clarity.

Referring to **Fig. 1A** and **Fig. 1B**, an exploded view and a cross-sectional view of a vessel **10** before a welding process are illustrated, correspondingly, according to one embodiment of the invention. The vessel **10** includes a cylindrical vessel's body **11** having an open end **12** and a cover **13**. The cover **13** has a welding part **14** and a brim part **15**. The purpose of the brim part **15** is to hold the cover **13** inside the vessel's body **11**. Therefore, a diameter of the cover **13** at the brim part **15** is equal to the inner diameter of the vessel's body **11**. A diameter of the cover **13** at the welding part **14** is less than the inner diameter of the vessel's body. Thus, an annular air gap **16** is provided between a vessel's welding portion **19** and a surface

**17** of the cover's welding part **14**, when the cover **13** is placed into the open end **12** of the vessel's body **11**.

The vessel **10** may be constructed of any suitable metal material having the required strength and forming characteristics for the particular application. It should be appreciated that the vessel's body **11** and the cover **13** can be made of the same material or different materials. Examples of the metal materials from which the vessel's body **11** and the cover **13** are made include, but are not limited to, aluminum, low carbon steel, brass, copper. It should be appreciated that alloys of these and other materials can also be used.

In order to provide a force required to weld the cover **13** to the vessel's body **11**, a high power pulsed magnetic field is generated around the vessel's body **11** at the place where the cover's welding part **14** is located inside the vessel's body **11**. A device suitable for providing a required magnetic pulsed magnetic field is known *per se*, and therefore its construction and operation will not be expounded herebelow. For example, the device described in U.S. Pat. No. 5,824,998 to the Assignee of this application, incorporated herein by reference, can be used for the purpose of the present invention. Such a device includes a welding induction coil, which can be configured in accordance with a specific application. In **Fig. 1B** the welding induction coil surrounds the vessel's body **11** and is indicated by a reference numeral **18**. An example of the configuration of the welding induction coil **18** suitable for the present invention will be described in detail hereinbelow.

Referring to **Figs. 2A-2D**, a sequence of stages of the welding process is illustrated, according to an embodiment of the invention. It should be noted that these figures are not to scale, and are not in proportion, for purposes of clarity. In operation, a pulsed magnetic force **F**, associated with the magnetic field generated by the welding induction coil, is applied to the welding portion **19** of the vessel's body **11** (see **Fig. 2A**). According to this embodiment, the welding portion **19** is located near the open end **12** of the vessel's body **11**. However, it should be understood that the location of the vessel's welding portion **19** is not limited to any part of the vessel's body **11** along its length.

The process of welding the vessel **10** for sealing thereof includes energizing the welding induction coil **18** to produce the pulsed magnetic force **F** for bending the vessel's welding portion **19** in a radially inward direction around the cover's welding part **14**. The welding starts at the moment when an edge **20** of the welding portion **19** contacts the surface **17** of the cover's welding part **14** (see **Fig. 2B**). During the welding, the front line **21**, defining the welding zone **WZ**, moves tangentially towards the brim part **15** (see **Fig. 2C**), thereby sealing the vessel (see **Fig. 2D**).

It should be understood that in order to provide the welding of the vessel's body and the cover owing to the mutual diffusion of the atoms, the pulsed magnetic force **F** should have a predetermined value. More specifically, the pulsed magnetic force **F** must have such a value so that the vessel's welding portion **19**, during its movement in the gap **16** towards the surface **17** of the cover's welding part **14**, could attain a speed sufficient for welding the vessel's body to the cover. For example, the applicants found that the welding can be established when an effective speed value of the vessel's welding portion **19** at the impact is in the range of 250m/sec-500m/sec and the apparent tangential speed $\mathbf{V_t}$ of the front line **21** is in the range of 1000m/sec-2500m/sec.

**Figs. 3A** and **3B** illustrate exemplary images obtained from the examination under an optic microscope (magnification: X100) of a cross-section of an etched interface of the joint between the vessel's welding portion **19** and the cover's welding part **14** made of two similar metals, such as low carbon steel and aluminum, respectively. **Fig. 3A** shows a typical flat shear-like welded interface, while **Fig. 3B** shows a typical wavy interface. The flat shear-like welded interface can be obtained when the angle between the vessel's welding portion **19** and the cover's welding part **14** at the impact is relatively small, while the wavy interface is obtained when the impact angle is relatively large. It should be noted that the magnitude of the angle when the flat shear-like welded interface changes to the wavy interface depends on the impact speed and type of material. As can be

appreciated by a person skilled in the art, such an image is a typical picture when a joint is obtained by a pulsed magnetic welding process.

Referring to **Fig. 4A** and **Fig. 4B**, an exploded view and a cross-sectional view of the vessel **10** before a welding process are illustrated, correspondingly, according to another embodiment of the invention. This embodiment distinguishes from that shown above in **Figs. 1A** and **4B** by the fact that the cover **13** here includes openings (one or more). In particular, two such openings indicated by a reference numeral **43** are shown in **Fig. 4A** and **Fig. 4B**. For example, when the vessel **10** is used as a container, the openings **43** can be required for inserting inlet and outlet pipes therein.

In this case, when the width of the metal material between the inner surface **44** of the openings **43** and the surface **17** of the cover's welding part **14** is small and/or the strength of the material of the cover is small, the pulsed magnetic force, applied for sealing the vessel as described above, can be high enough in order to cause a collapse of the cover's welding part **14** and to deform the openings **43**. In order to avoid this detrimental phenomenon, a technological plug **41** can be utilized together with the cover **13**. The technological plug **41** has one or more pins **42** (two such pins **42** are shown in **Figs. 4A** and **4B**) configured for inserting them into the openings **43** of the cover **13** and holding therein during the energizing of the welding induction coil **18**. After the energizing step, the technological plug **41** can be detached from the sealed vessel. Preferably, the dimension of the pins is such that they could fill the space of the openings, thereby providing reinforcement to the cover **13**. The pins **42** are made of a material as hard as the material of the cover **13** or even harder than the material of the cover, e.g., hardened steel.

It should be noted that in accordance with yet an embodiment of the invention, when the technological plug **41** is utilized for preventing deformation of the openings **43**, the cover **13** can be without the brim part **15**. In such a case, preferably, the diameter of the plug **41** conforms to the inner diameter of the vessel's body **11**, thereby holding the plug together with the cover **13** within the

vessel's body **11**. After the sealing process, the plug **41** is detached from the vessel's body **11**.

Referring to **Fig. 5** a cross-sectional view of the vessel **10** before a welding process is illustrated, according to a further embodiment of the invention. This embodiment distinguishes from that described in **Figs. 1A** and **1B** by the fact that the vessel's body **11** is expanded at the open end **12** before the welding process, thereby forming an expanded zone **A**. A diameter $D_A$ of the vessel's body **11** at the expanded zone A has a value larger than that of the diameter $D_V$ of the vessel's body **11** at its remaining portion. The expanded zone **A** is provided for the better holding of the cover **13** within the vessel's body **11**. Thus, before the welding process, according to this embodiment, a value of the diameter $D_{CB}$ of the cover brim part **15** should be about the value of the diameter of the expanded zone **A** (i.e., $D_{CB} \approx D_A$), while the diameter $D_{CW}$ of the cover welding part **14** has to comply with the following inequality: $D_V \leq D_{CW} < D_A$.

Although no openings are shown in **Fig. 5** in the cover **13**, it can be clear to a versed person that when required, the cover can have one or more openings. In such a case, the technological plug (**41** in Fig. 4A) can be used in order to protect the cover from deformation during the welding process.

Referring to **Fig. 6**, a cross-sectional view of the vessel **10** before a welding process is illustrated, according to yet another embodiment of the invention. This embodiment distinguishes from that described in **Figs. 1A** and **1B** by the fact that the vessel's body **11** has an undulated zone B near the open end **12**. The undulated zone B is formed on the vessel's body **11** before the welding process and begins at a distance equal to the size of the cover welding part **14**. The purpose of the undulated zone B is to provide better holding of the cover **13** within the vessel's body **11**. Hence, a diameter $D_B$ of the undulated zone B has a value smaller than the diameter $D_V$ at the remaining portion of the vessel (i.e., $D_B < D_V$). According to this embodiment of the invention, the value of the diameter $D_{CB}$ of the cover brim part **15** should be about the value of the diameter of the vessel's body **11** (i.e., $D_{CB}$

$\approx D_V$), while the diameter $D_{CW}$ of the cover's welding part **14** has to comply with the following inequality: $D_B < D_{CW} < D_V$.

Referring to **Figs. 7A-7C**, cross-sectional views of the vessel **10** before a welding process are illustrated, according to a still further embodiments of the invention. These embodiments distinguish from those described above in the fact that an insulated cylinder **71** is put on the vessel's body **11** for a further reinforcement of the vessel's body **11** during the welding. Thus, preferably, the inner diameter of the insulated cylinder **71** is equal to the outer diameter of the vessel's body **11**.

Referring to **Fig. 8A** and **Fig. 8B**, a prospective view and a cross-sectional view of the welding induction coil **18** are illustrated, correspondingly, according to an embodiment of the invention. The welding induction coil **18** includes a one-turn coil **81** having a canal **82** formed into the coil's body for providing a passage of cooling liquids therethrough. For example, the canal **82** can be drilled during fabrication of the coil. Two inlets **83** and **84** communicating with the canal **82** can be used for input and output of liquid, (e.g. water) passing through the coil **18** for cooling thereof during the welding process. Three other technical inlets **85** created in the coil's body during the drilling of the canal **82** are closed by plugs **86**, in order to avoid the leakage of the cooling liquid. The inlets **83** and **84** are connected to a liquid supply line (not shown). When required, the liquid supply line can be equipped with a liquid pump. When required, the liquid supply line can pass through a cooling system. The cooling system is known *per se*, and can be of any conventional kind, e.g., a radiator.

The welding induction coil **18** includes two electrodes I and O coupled to an electric power supply source. For example, the power supply source described in U.S. Pat. No. 5,824,998 to Assignee of this application and incorporated herein by reference can be suitable for the purpose of the invention.

In operation, the vessel's body **11** can be placed into a working zone **89** of the welding induction coil **18**, preferably, at a distance of about 1-3 mm from an inner surface **90** of the one-turn coil **81**. The providing and holding of the vessel's

body **11** within the welding induction coil **18** can be done by any appropriate known means. For example, the vessel's body can be driven to the welding zone of the working induction coil by means of a pneumatic cylinder (not shown) or by a hydraulic cylinder (not shown). The working voltage suitable for the purpose of the invention is in the range of about 3kV to 25 kV. This voltage can provide a pulsed electric current across the one-turn coil **81** having the amplitude of about 10kA to 1000kA.

As such, those skilled in the art to which the present invention pertains, can appreciate that while the present invention has been described in terms of preferred embodiments, the concept upon which this disclosure is based may readily be utilized as a basis for the designing of other structures, systems and processes for carrying out the several purposes of the present invention.

It is apparent that although the examples of the vessel of the present invention were shown for the vessel body portion having a circular cross-section, the sealing method of the present invention can be applied, *mutatis mutandis*, for the sealing of a vessel having an arbitrary cross-sectional shape.

It should be appreciated that the method described above can be used for sealing a pipe from two open sides. The pipe includes a vessel's body having two open ends.

Although an example of the welding induction coil **18** having one-turn coil **81** is described above, it should be apparent that the working induction coil can also be a multi-turn coil equipped with a field-shaper.

Moreover, any reference to a specific implementation in terms of usage of the induction coil is shown by way of a non-limiting example.

Also, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting.

In the process claims that follow, alphabetic characters used to designate claim steps are provided for convenience only and do not imply any particular order of performing the steps.

It is important, therefore, that the scope of the invention is not construed as being limited by the illustrative embodiments set forth herein. Other variations are possible within the scope of the present invention as defined in the appended claims and their equivalents.